Virtual Reality Visualization of Sustainable Management Practices for Forest Carbon and Climate Change

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Abstract: Landscape visualization can help increase awareness of the benefits of sustainable forest management practices through immersive visualizations, which can allow forest landowners to understand the many benefits of these management practices. This research aims to create highly-realistic virtual forests which are based on scientific forest data. The virtual forest scenarios visually communicate the impact of sustainable forest management strategies on forest health, visual character, and ability to sequester carbon. Forest tree models are created using a hybrid approach of photogrammetry and 3D modeling in Maya, and are then imported into Unity, a real-time game design engine. Using Unity's Hight Definition Render Pipeline (HDRP), the forest scene achieves high levels of realism through the use of shaders and material settings that capture light, shadow, and wind movement. Iterative review of forest scenes by forest ecologists ensures its visual and scientific correctness, followed by adjustments to the scene to improve its visual quality and coherence. The constructed scenes showed forests in different conditions and the result of various natural and human influences.

Keywords: Forest, virtual, render, visualization, 3D, Unity

1 Introduction

1.1 Incentivizing Sustainable Forest Management

Sustainably managed forests are increasingly recognized as powerful tools in addressing climate change through their ability to sequester carbon more effectively than typically-managed forests. Sustainable forest practices play a critical global role as sustainable carbon sinks and are the most potent natural climate solutions in terms of their potential for active greenhouse gas removal from Earth's atmosphere (FARGIONE 2018). To promote the use of sustainable forest practices, it is critical to understand the economic, environmental, and social factors which can support the future development of forest operations (MARCHI et al. 2018). Yet sustainable forest management is challenging to incentivize among forest landowners, despite evidence that shows that over the long run these beneficial practices result in a healthier forest with more eligible trees for harvesting and better ability to sequester carbon.

Part of the reason why sustainable forest management practices can be challenging to incentivize is related to the connection between landscape aesthetics and ecology. Humans have a tendency to respond emotionally to the visual character of the landscape, and possess an innate desire to live in and visit places that are beautiful (GOBSTER et al. 2007). While the visual quality of the landscape is somewhat dependent on observer

Journal of Digital Landscape Architecture, 7-2022, pp. 392-400. © Wichmann Verlag, VDE VERLAG GMBH · Berlin · Offenbach. ISBN 978-3-87907-724-3, ISSN 2367-4253, e-ISSN 2511-624X, doi:10.14627/537724038.

preference, positive visual associations with the landscape share a common background across sociological and cultural groups and largely correspond with biological diversity (GARCIA-ABRIL et al. 2019). While sustainable forestry practices lead to a more positive long-term aesthetic than their conventional counterparts, in the short term, even sustainable forest management practices can infringe upon the visual character of the landscape. This presents a challenge for landscape visualization projects.

1.2 Landscape Visualization and Forestry

Landscape visualization techniques have long been recognized as a method to bridge the gap between sustainable practices and public perceptions (LANGE 2001), these techniques have been limited by the computational requirements of simulating entire landscapes and the high level of programming skill required, relegating landscape visualization to be an underutilized tool in scientific communication (BELL 2001). Ever-evolving imaging technology has allowed us to digitally model, visualize, and simulate realistic landscapes for some time (LEWIS 2012). These visualizations have become a common tool for experts to present their work to citizens for evaluation while reducing the chance that information will become distorted (ORLAND et al. 2001). It has been shown that multiple professional groups, including private and public landscape and environmental planning offices, regional planning offices, and visualization professionals largely believe that the use of 3D visualizations can be beneficial to landscape planning (PAAR 2006). Lastly, landscape visualizations can help uncover how peoples' differing relationships to place can influence their reactions to a virtual representation of that place, clarifying our understanding of the relationship between a sense of place and a person's mental image of place (NEWELL & CANESSA 2018).

These digital tools can help increase awareness of the benefits of sustainable forest management practices through immersive visualizations, which can allow forest landowners to understand the many benefits of these management practices. Viewer perception of visual quality of the landscape due to forest harvest depends on many factors in both the forest and the audience (ZUBE et al. 1982). While we cannot account for all such factors, we can use digital tools to reliably design interfaces for visualizing forest growth visualization, whether they represent exact or generalized forest stand behavior (HAUHS 1999). A range of digital tools to simulate forest behavior have been explored over the past several decades. Among these are the use of GIS used to visualize scenic changes as a result of forest harvesting (BERGEN 1995), the development of a virtual reality forest landscape visualization system to simulate the changes of forest landscapes that occur as a result of natural processes or man-made disturbances (LIM 2003), ecological and silvicultural modelling of individual tree structure for decision support in forest management (FENG 2012), and use of artificial neural networks in recent years (NITOSLAWSKI et al. 2021).

1.3 Realistic Data-Driven Virtual Forest Visualization

These digital approaches have been shown to be reliable and powerful in their ability to simulate forest response to internal and external conditions. However, nearly all these tools were developed with the primary intent to convey technical information with little to no emphasis on immersive realism, limiting their ability to reach broad audiences. Scientifically accurate yet highly simplified visualizations, while technically correct, do not communicate the intuitive aspects of the landscape which are so critical to changing perceptions and attitudes. Our research addresses this limitation by elevating the realism of the virtual forest setting to an unprecedented level while also being based on scientific forest data. It has been shown that this level of realism in landscape visualizations has a measurable impact on viewer perception. Scientifically accurate, realistically-rendered virtual forests is an emerging area of research; recent projects include immersive modeling of an endangered eucalyptus woodland (CHANDLER et al. 2021), and forecasting 50 years of climate changes to a northern Wisconsin forest and visualizing these changes in virtual reality (HUANG et al. 2021).

When compared to static low-resolution images, the use of realistic landscape visualizations, particularly in virtual reality settings, has been found to reduce choice error and improve engagement in respondents (MATTHEWS 2017). Highly realistic virtual reality forest simulations have been shown to be reliable in replicating landscape cognition attributes that occur when viewing a physical landscape site (SHI 2020). We believe that for people to open their minds and rethink perceptions and beliefs about forestry, they must be able to perceive the "sense of place" of the sustainably-managed forest, communicated to the viewer through visualization of bark and leaves, soil and water, water and wind movement, light, and sound. By focusing on communicating the benefits of sustainable forest management practices to forest landowners through the use of highly-realistic three-dimensional virtual reality (VR) landscape visualizations, this work has the potential to increase adoption of sustainable forestry practices among forest landowners.

2 Methods

Our project team is a team of students, faculty, and staff in landscape architecture and forestry. The team works collaboratively to develop virtual forest scenarios which visually communicate the impact of sustainable forest management strategies on forest health, visual character, and ability to sequester carbon. The team's visualization workflow begins with developing a narrative based around a particular sustainable forest management practice such as deer exclusion fencing, avoiding high grading, or invasive plant species removal. The team's forestry members storyboard the visual changes to the forest, drawing from photographs to communicate detailed aspects of the appearance of the forest before, during, and after a sustainable practice is implemented. From the storyboard a digital terrain model is created using ArcGIS, Rhinoceros 3D, and Unity, a real-time game design platform. Real-world geospatial information is used to recreate a physical place typical of a northern hardwood forest where a particular practice would ideally be used (Figure 1).

Fig. 1: Unity forest model from above showing low LOD tree models

In Unity, the terrain is textured using terrain painting brushes with imagery sourced from photographs of forest floors including leaf litter, wet or dry soil, sand, rocks, roots, or moss. Tree models are created using a hybrid approach of photogrammetry and 3D modeling, where the tree roots and lower trunk are photoscanned and imported into Maya, and the upper trunk and branches are 3D modeled onto the photoscanned model. The hybrid tree is then imported into Unity, where leaf materials are added to the branches using photographed leaf specimens gathered from the field. (Figure 2). This use of field specimens is an increasingly common practice that can help capture the visual character of the landscape being depicted (DEMETRESCUE et al. 2020).

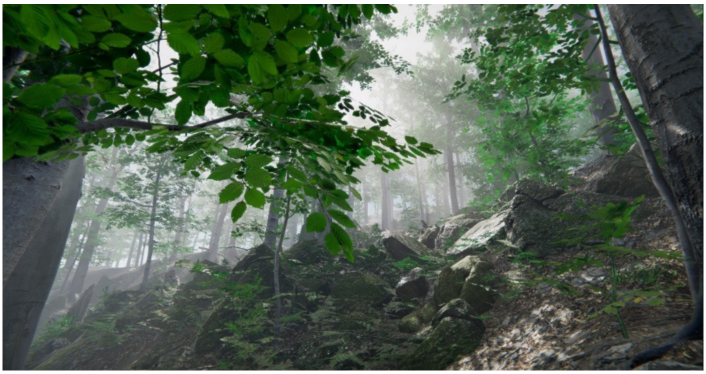

Fig. 2: Close-up view of leaf materials created with specimens gathered from the field

Because the scene is created using Unity's High-Definition Render Pipeline, realistic lighting and shaders can be used to create immersive realistic effects. The tree leaves are given detailed textures and wind movement using advanced foliage shaders. All trees and leaves are assigned four Levels of Detail (LOD) so that they automatically adjust their polygon count relative to the viewer's closeness to the model. The use of LODs allows the team to use hundreds of highly detailed trees in their forest models without sacrificing rendering speed. Trees and understory vegetation are placed individually on the terrain to ensure that their position on the terrain and proximity to other vegetation reflects the typical character of the forest with or without sustainable forest management practices in place (Figure 3).

Fig. 3: Eye-level view of photoscanned trees representing low-quality timber stand

Iterative review of forest scenes by the entire project team to ensure its visual and scientific correctness, followed by adjustments to the scene to improve its visual quality and coherence. The constructed scenes showed forests in different conditions and the result of various natural and human influences (Table 1).

Table 1: Scene description and visual effects presented in this study

Scene	Description	Visual Effects
High-grading	a forestry practice that removes the high quality, larger trees and results in degradation of the forest quality, diversity and resilience over time	Removal of large trees creating an open and degraded patchy forest (see Figure 4)
Sustainable Forest Management	Forestry interventions that improve tree health and species mix	In this case, thinning crowded, unhealthy, and undesirable species to allow preferred species to grow (see Figure 4)
Deer Browse	Demonstrating forest effects of deer herbivory on young trees and shrubs over time	Forest with understory trees and shrubs are consumed by deer; forest becomes devoid of new growth and understory (see Figure 5)
Invasive Species	Non-native to the ecosystem under consideration and cause economic or environmental harm or harm to human health	Invasive species are shown taking over forest and then compared to forest after removal of invasive wherein preferred species are able to thrive (see Figure 6)

To achieve these outcomes, adjustments included: removing or adding mature trees or poor-quality trees to alter the density and health of the forest canopy; increasing ground vegetation growth to show tree species regeneration of growth of invasive species; and adding structures such as deer exclusion fencing and animated deer models to demonstrate the impact this fencing has on healthy forest regeneration (Figure 4). During the animation of these scenes, additional Unity shaders are used to highlight or outline specific trees at specific moments in the narrative so that they become more noticeable (Figure 5). Finally, post-processing of the Unity animations in Adobe After Effects includes text and graph overlays such as a carbon graph, voiceover animation, and video export (Figure 6).

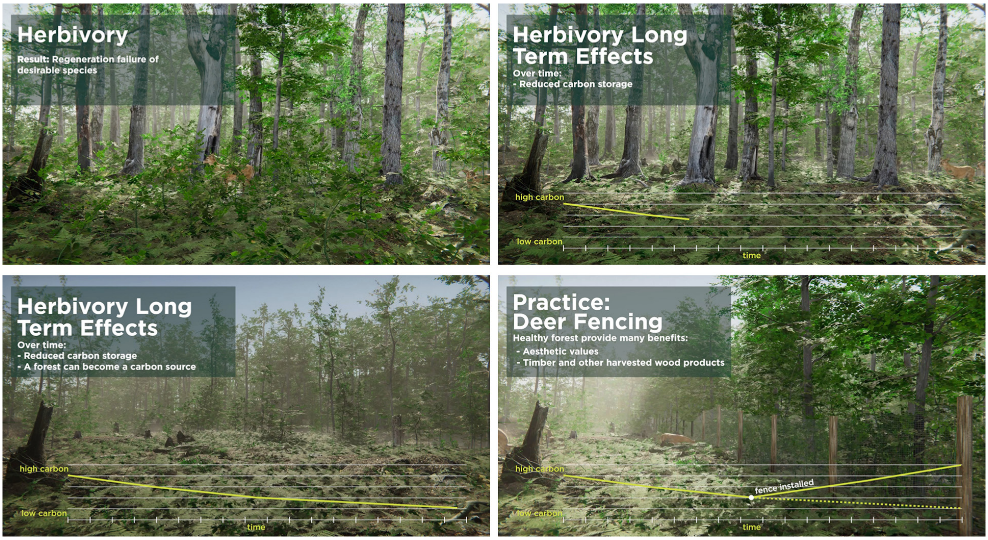

Fig. 4: Stills from final animation sequence showing long-term forest stand degradation and related carbon storage as a result of deer browse, compared with forest regeneration as a result of deer exclusion fencing (note: timescale is generalized for communication purposes but intended to reflect decades)

Fig. 5: Example of fill and outline shader colorization to highlight existing invasive species (left) and hypothetical growth of desirable tree species (right)

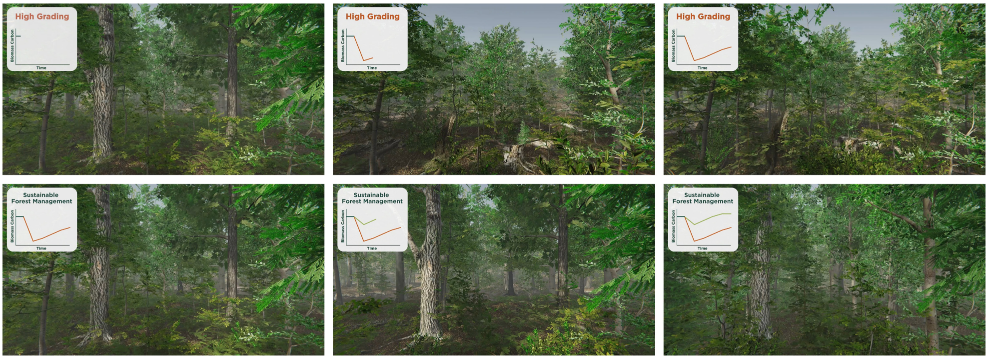

Fig. 6: Stills from final animation sequence showing forest stand degradation as a result of high grading (top), compared with healthy forest regeneration from sustainable forest management practices (bottom). Graphs in the top left of each image show the carbon stored in the aboveground biomass

As an innovative approach to overcoming knowledge gaps in forestry and climate change, we have thus-far tested materials in peer environments. Near-term plans are to include visualizations in various studies that will deploy videos to forest decision-makers and allow us to test effects of visualizations on forest decision-makers, in time savings by field professionals to educate and engage, and in the level of confidence that interventions will result in the intended outcomes. This is a critical next step in our research that will allow us to evaluate the effectiveness of the intervention and how to continue improving our communication techniques. Stephen Sheppard's vast body of work in sharing visualizations with communities to effect policy is an excellent example of developing a program to recruit people and help them make sustainable decisions, for example in using visualization to communicate forest management planning with stakeholder groups (SHEPPARD & MEITNER 2005).

3 Discussion

One of the most critical parts of this workflow is the flexibility of Unity to easily integrate a wide range of file types such as photoscans, digitally modeled vegetation, materials, shaders, animated objects, and interactive objects. It is especially important that all scenes be fully detailed in 360 degrees so that it can be used to create a range of media outputs. The ability to seamlessly use the same model for many visualization types is critical; from still images and movies to a full virtual reality walkthrough where viewers can explore and interact with the environment. Further customization of the Unity environment is possible either through instant download of assets from the Unity Asset Store, or through coding in Unity's C# scripting language.

Real-time rendering allows quick production of realistic renderings and animation without adding significant production time, allowing us to export high-quality animations directly from Unity using screen recording instead of exporting renderings. The ability to quickly export animations in the time it took to record a real-time walkthrough was influential in allowing the team to make small changes to the forest scenes without the concern of adding significant rendering time to the project. This translated to an increased openness to a flexible and continuous iterative process that allowed us to create updated animations throughout the projects.

The team's completed virtual reality visualizations cover a range of well-established sustainable forest management practices, and are intended to communicate the benefits of these practices to increase their adoption by forest landowners. Future applications could include visualizations of fire impacts, logging practices, forest type regimes (e. g., plantation forestry), agroforestry, and forests and trees in the built environment (urban forestry). Further, there is the potential to move to visualizing experimental practices, such as the practice of slash walls in place of deer exclusion fencing. For these practices, there is little or no past data or photography that we can rely on for our visualizations. In these cases, our team's visualizations may well be useful in establishing the potential changes to the character and structure of the forest as a result of these new practices in sustainable forest management.

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